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Award Number: W81XWH-09-1-0062

TITLE: Image-Based Biomarker of Breast Cancer Risk: Analysis of Risk Disparity Among Minority Populations

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REPORT DATE: March 2011

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command  
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release; distribution unlimited

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 01-03-2011		2. REPORT TYPE Annual		3. DATES COVERED (From - To) 1 Mar 2010 - 28 Feb 2011	
4. TITLE AND SUBTITLE Image-Based Biomarker of Breast Cancer Risk: Analysis of Risk Disparity Among Minority Populations				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER W81XWH-09-1-0062	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Dr. Fengshan Liu  E-Mail: fliu@desu.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Delaware State University Dover, DE 19901-2202				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT With this funded project, we will enhance DSU breast cancer research resources. We will train a cadre of DSU faculty to study breast cancer and establish an independent breast cancer research program at DSU by performing a joint DSU-UPENN research project focused on breast cancer risk disparity in minority populations. During last year, we focused on joint training and research activities. We completed the transfer of clinical data from ACRIN DMIST study; we identified limitations of the current standard methods for the estimation of risk biomarkers (which require only a single input image), and developed a conceptual design of a biomarker estimation system to support the analysis of breast cancer risk racial disparity and the prospective refinement of the risk prediction methods.					
15. SUBJECT TERMS Breast Cancer, Risk Disparity, Minority Population, Image-Based Biomarker, Training Program					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  UU	18. NUMBER OF PAGES  19	19a. NAME OF RESPONSIBLE PERSON USAMRMC
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code)

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## **1. Introduction**

With this funded project, we will enhance DSU breast cancer research resources. We will train a cadre of DSU faculty to study breast cancer and establish an independent breast cancer research program at DSU by performing a joint DSU–UPENN research project focused on breast cancer risk disparity in minority populations. During last year, we focused on joint training and research activities. We completed the transfer of clinical data from ACRIN DMIST study; we identified limitations of the current standard methods for the estimation of risk biomarkers (which require only a single input image), and developed a conceptual design of a biomarker estimation system to support the analysis of breast cancer risk racial disparity and the prospective refinement of the risk prediction methods.

## **2. Body**

With this funded project, we will enhance DSU breast cancer research resources by: improving our expertise in translational and clinical breast cancer research; developing methods for computing image-based biomarkers for breast cancer risk, as well as methods for biomarker analysis of risk disparity; developing a database of clinical biomarkers computed from images of minority women; refining the existing and developing novel data mining techniques to determine the relationship between risk and image-based biomarkers. The improvement will support further growth of a sustained breast cancer research program at DSU and help establish us as a mid-Atlantic center for analysis of breast cancer risk and risk disparity among minority women.

The specific objectives of this training program include: (1) extending the skills of a select cadre of DSU faculty, so that they may become accomplished, influential and competitive breast cancer researchers; (2) establishing an independent breast cancer research program at DSU by performing a joint DSU–UPENN research project focused on breast cancer risk disparity in minority populations; and (3) producing a corpus of high quality published work and develop a portfolio of independently funded research grants at DSU to support a sustained breast cancer research program.

## 2.1 Objective 1

**Extend the skills of a select cadre of Delaware State University (DSU) faculty, so that we may become accomplished, influential, and competitive breast cancer researchers.**

- o Organize specific training for selected DSU faculty, aimed at complementing our individual scientific background. (Y1-4)

### **Graduate Courses taken at UPENN**

#### **Spring 2011 Course**

Dr. Charlie D. Wilson took:

GCB 535 Intro to Bioinformatics

Course Description: The course provides a broad overview of bioinformatics and computational biology as applied to biomedical research. Course material will be geared towards answering specific biological questions ranging from detailed analysis of a single gene through whole-genome analysis, transcriptional profiling, and systems biology. The relevant principles underlying these methods will be addressed at a level appropriate for biologists without a background in computational sciences. This course should enable students to integrate modern bioinformatics tools into their research program

#### **Spring 2010 Semester**

Dr. Xiquan Shi took:

#### **CAMB 512-001 2010A. Cancer Biology & Genetic: Cancer Biology and Genetics**

The course objective is to introduce the students to important and timely concepts in Cancer Biology and Cancer Genetics. The lectures are organized into four broad thematic groups: A) Cell-Autonomous Mechanisms (e.g., tumor suppressor and oncogene function, DNA repair pathways, senescence, apoptosis); B) Non Cell-Autonomous Mechanisms (e.g., tumor microenvironment, hypoxia, angiogenesis); C) Organ Systems (e.g., pancreatic cancer, hematopoietic malignancies); and D) Therapeutic Approaches (e.g. protein kinase inhibitors, immunotherapy, radiation therapy). The organizers, along with faculty from the School of Medicine, the Wistar Institute and CHOP, with expertise in the corresponding areas provide lectures for the course. The students are expected to present, and participate in discussions of one or more key recent papers at Journal

Clubs that are held at the end of each thematic group. There will be mid-term and final exams of short essays relevant to the lectures.

### **Spring 2010 Semester**

Drs. Fengshan Liu and Dragoljub Pokrajac took:

#### **BE545/CIS 537 Biomedical Image Analysis**

This course covers the fundamentals of advanced quantitative image analysis that apply to all of the major and emerging modalities in biological/biomaterials imaging and in vivo biomedical imaging. While traditional image processing techniques will be discussed to provide context, the emphasis will be on cutting edge aspects of all areas of image analysis (including registration, segmentation, and high-dimensional statistical analysis). Significant coverage of state-of-the-art biomedical research and clinical applications will be incorporated to reinforce the theoretical basis of the analysis methods.

### **Spring 2010 Semester**

Dr. Charlie Wilson took:

#### **GCB/CAMB 752 SEMINAR IN GENOMICS**

Recent papers from the primary genomics literature will form the core material for the course. Each 3-hr session will feature a major topic or set of related topics in Genomics, with student presentations (usually two per session) centered on papers selected within the topic area(s). While the “presenting” student will give a 10- 15 min introduction to the paper and will show PowerPoint slides of the data in the paper, all students in the class are expected to have read and to be prepared to discuss the papers presented

#### **Report: DSUPENN Breast Cancer Seminar Series**

DSUPENN Breast Cancer Seminar Series are organized to provide training in breast cancer research to DSU faculty including Fengshan Liu, Xiquan Shi, Charlie Wilson and Dragoljub Pokrajac and students at Delaware State University. Invited speakers of the biweekly seminar series include nationally renowned breast cancer researchers from UPENN Medical School, nearby hospitals and other institutions.

---

DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 3pm, March 5, 2010  
Presentation Title: Genetic Counseling and Testing for BRCA1 and BRCA2 Mutations in African American Women  
Invited Speaker: Chanita Hughes Halbert, University of Pennsylvania

Abstract:

This presentation will describe research that is being conducted to improve decision making about genetic testing for inherited breast cancer risk among African American women at increased risk for hereditary disease. Research on psychological and behavioral outcomes following genetic counseling will also be discussed.

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DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 3pm, March 26, 2010  
Presentation Title: Treatment of Breast Cancer- The Medical Oncologist's Approach Multimodality  
Invited Speaker: Keerthi Gogineni, University of Pennsylvania

Abstract:

I will be talking about the fundamentals of breast cancer, with a focus on the medical treatment of the disease.

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DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 3pm, April 9, 2010  
Presentation Title: Breast Cancer Radiation Therapy Treatment Techniques  
Invited Speaker: Timothy Zhu, University of Pennsylvania

Abstract:

We will present techniques typically used for radiation therapy for breast cancer, including conventional techniques, IMRT, brachytherapy, and other special techniques.

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DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 3pm, April 23, 2010  
Presentation Title: Computer-aided diagnosis in mammography: from the desktop to the clinic  
Invited Speaker: Robert Nishikawa Timothy Zhu, The University of Chicago  
University of Pennsylvania

Abstract:

Computer-aided diagnosis (CAD) for mammography started over 25 years ago and over the years has been developed into a commercial product that is used routinely clinically. In this talk I will describe the development of CAD and the current evidence of its clinical effectiveness.

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DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 3pm, May 7, 2010  
Presentation Title: Multimodality Breast Imaging Biomarkers for Cancer Risk Estimation and Personalized Screening  
Invited Speaker: Despina Kontos, University of Pennsylvania

Abstract:

Growing evidence suggests that increased parenchymal pattern complexity is associated with a higher risk for developing breast cancer. Currently, the most widely used methods to quantify parenchymal complexity rely on semi-automated techniques that estimate the percent of the dense tissue in mammograms. Although useful for



breast cancer risk estimation, these methods are highly subjective and difficult to standardize, potentially limiting their applicability to the general population. Emerging tomographic breast imaging modalities offer the opportunity to develop novel imaging biomarkers for quantifying parenchymal pattern complexity that may ultimately result in more accurate measures to estimate breast cancer risk. This lecture will provide an overview of emerging techniques to perform parenchymal pattern analysis using imaging modalities such as digital breast tomosynthesis (DBT), magnetic-resonance imaging (MRI) and breast ultrasound (US). Improving breast cancer risk estimation using multimodality imaging biomarkers could be of great clinical advantage for offering customizing screening recommendations, tailoring individual treatments, and forming preventive strategies, for women at a higher risk of breast cancer.

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### DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 3pm, November 19, 2010  
Presentation Title: Review of Breast Cancer Basics Multimodality  
Invited Speaker: Sara C. Gavenonis, MD, University of Pennsylvania

#### Abstract:

This lecture is an overview of topics covered during the 2009-2010 seminar series. The clinical “world” of breast cancer will be broadly reviewed, including epidemiology, anatomy, pathology, imaging, and current clinical oncology. Current and future research directions will also be covered, with focus on breast imaging research.

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### DSUPENN Breast Cancer Seminar Series

Location: ETV131  
Time: 12pm, December 17, 2010  
Presentation Title: Advanced Design of Anthropomorphic Software Breast Phantoms: Work in Progress  
Invited Speaker: Dr. Predrag Bakic, PhD, University of Pennsylvania  
Dr. David Pokrajac, PhD Delaware State University

**Abstract:**

Validation and optimization of clinical breast imaging systems is a complex task due to the large number of parameters which may affect the performance. Preferred validation approach is based upon clinical trials, which are usually long, costly and require repeated exposure of the same patient volunteers. An alternative approach is to use software anthropomorphic breast phantoms in preclinical validation to select promising system configurations for comprehensive clinical trials. The University of Pennsylvania has been at the forefront of software breast phantom development and virtual clinical trial research. Today's lecture will review existing software phantom designs and applications. In addition, we will present advanced phantom design developed in collaboration with Delaware State University, aimed at an accelerated and scalable phantom generation. An emphasis will be put on computational geometry and computational complexity issues and the implementation of the software.

**Other seminars attended by Fengshan Liu, Xiquan Shi, Charlie Wilson and Dragoljub Pokrajac**

Title: Breaking Barriers: Caring for the Underserved and Undocumented

Objectives:

- ☐ *Discuss the limitations to healthcare encountered by a migrant population*
- ☐ *Understand the value of outreach in the development of the physician*
- ☐ *Describe our experience with providing healthcare to a migrant population*

Jack Ludmir, MD

Professor and Chair, Department of Obstetrics and Gynecology, Pennsylvania Hospital

Vice Chairman, Department of Obstetrics and Gynecology

Director of Obstetrical Services, University of Pennsylvania School of Medicine

President of Women and Children's Health Services

Date: January 19, 2011 (Wednesday)

Time: 12:00 - 1:00 PM

Location: Seminar Room 253, BRB II/III (Biomedical Research Building 421 Curie Blvd.) UPENN

- o Augment the faculty training by frequent communications with collaborating mentors and other renowned breast cancer researchers, by: (Y1-Y4)

DSU faculty traveled to UPENN to attend the above mentioned seminars, and to meet with the collaborating mentors on the same trips. Meetings are always scheduled after the seminars at UPENN. UPENN collaborating mentors, particularly Andrew Maidment and Predrag Bakic come to DSU to organize and attend the DSUPENN Breast Cancer Seminar Series. Communications are made between the seminar speakers, the mentors and DSU faculty.

- o Perform research training at Penn, as a part of the research project focused on breast cancer risk disparity in minority populations (proposed in Objective 2). (Y1-Y2, with gradual transfer of the research project from Penn to DSU in Y3-Y4)

Please see the report in the section Objective 2.

- o Validate success of the faculty training program by semi-annual Mentorship Committee meetings for each DSU faculty, and annual teleconferences with and bi-annual visits by external Advisory Committee.

On Wednesday, Nov. 3, 2010 at 3:30-4:30pm, a teleconference meeting of the DoD award Advisory Committee was organized by Drs. Maidment, Liu, and Bakic, and attended by all the DSU faculty supported on the grant, as well as Drs. Chanita Hughes and Timothy Rebbeck from Penn. The discussed issues include our progress on the grant, future research steps related to the genetic analysis project aims, as well as the long term aim of establishing a regional Breast Cancer Disparity Center at DSU.

DSU faculty met with UPENN mentors on June 24, 2011, January 24, 2011 and August 9, 2010 to discuss the progress and the future work of each DSU faculty.

## 2.2 Objective 2

### **Establish an independent breast cancer research program at DSU by performing a joint DSU/Penn research project focused on breast cancer risk disparity in minority populations**

- o Obtain appropriate IRB approvals for the proposed research. (months 1-6 of Y1)

Included in Year 1 Report.

- o Develop a database of anonymized clinical mammograms and patient metadata, obtained retrospectively from ACRIN DMIST and Penn PPG trials. (Y1-Y2)

In Spring 2011 we completed the transfer of all mammograms requested from the ACRIN 6652 study, including ~11,000 anonymized, previously acquired cases. We copied all the images at DSU and UPENN backup drives, and developed and developed a storage service (MIRC) database to host the ACRIN clinical data, and support further analysis of risk biomarkers.

During the last year we developed an SQL based database query aimed at identifying cases with only partial breast visualization per each mammogram. Such cases require attention as they cannot be analyzed by the currently available methods for the estimation of image-based risk biomarkers; these methods are designed to expect as input a single mammographic image. We have also analyzed the database of anonymized clinical images previously acquired within the NIH Program Project Grant supported clinical study at the University of Pennsylvania, focused on multimodality clinical breast imaging. The study include mammograms, digital breast tomosynthesis (DBT) images, breast MRI images, ultrasound images, and breast PET images of the same patient. Goal of the analysis was to familiarize with standard DICOM format of medical images, and to write a Matlab code for extracting and processing metadata from images.

We utilized SQL query to search for cases with only partial breast visualization. For that purpose, we extracted cases having more than 4 mammograms per exam, (i.e., more than 2 per view). A standard mammographic exam involves 4 images (2 views for each breast). A larger number of images may occur due to incorrect breast positioning , or for the breasts of larger size which needed more than one mammogram per view for complete coverage. Our database search task was designed in order to investigate the prevalence of cases with large breast size preventing correct density estimation. We performed the SQL database search of 657 patients with mammography exams, and after the visual confirmation of indicated images we found 85 (i.e., 13%) cases with large breast size. Such a prevalence suggests that we should develop a strategy for calculating breast density in cases with multiple mammograms per view due to the large breast size. This strategy may include merging multiple images to produce a single mammogram (which can be used for density estimation) or developing a method for combining breast density values estimated from several mammograms of the same breast.

In order to validate the proposed approaches, we plan to use simulated mammograms of the breast software phantoms originally developed at the University of Pennsylvania. In preparation of this task, during the last year we have worked on the refinement of breast tissue modeling, to allow for faster generation of mammograms with the resolution comparable to the clinical images. Images of the breast software phantom previously developed at the University of Pennsylvania sometimes include quantization artifacts due to the large voxel size. Increasing the phantom voxel size (above 100-200 microns) requires a prohibitively long simulation. In order to address this limitation, during the last academic year, we have also developed a new method for generating anthropomorphic software breast phantoms to be used for synthesizing breast images.

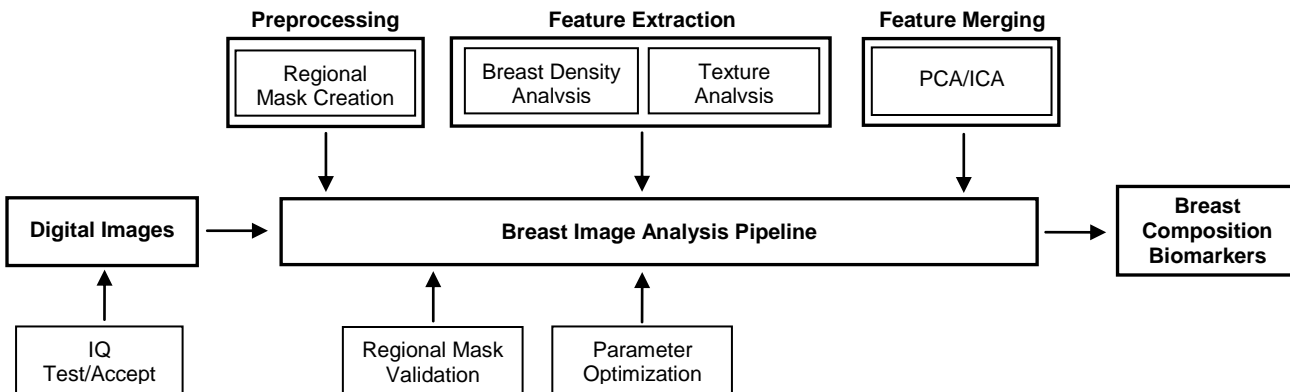
The new method allows for faster generation of phantoms with small voxel size, and provides better control of the parameters defining simulated anatomical structures. The new simulation method preserved the concept of region growing but is optimized to allow for faster simulation. The new method also includes an improved thickness control of the simulated skin and Cooper's ligaments. We designed and implemented the new method in Matlab and analyzed its asymptotic spatial and temporal complexity. We experimentally evaluated temporal complexity by generating more than 400 phantoms of different sizes, resolutions, thickness and shapes of the compartments. The phantoms were generated with various voxel sizes in the range of 25-10000 micrometers. The simulation time as function of the voxel size, number of compartments and thickness was approximated using the power regression. We also performed a visual comparison of the phantoms generated at different voxel size. We experimentally demonstrated the power exponent (equal to the slope in the log-log graph) w.r.t. the voxel size of 2.15 in contrast to the slope of 3.89 for the old method. This is reflected in a progressively faster simulation for phantoms with voxel size smaller than 200 micrometers. Specifically, we were able to generate phantoms at 50um and 25um resolutions which are not feasible by region growing. Generating phantoms with voxel size below 200 micrometers is of importance for reducing quantization artifacts in simulated phantom images, since clinical x-ray detectors currently produced with the pixel pitch down to 50 micrometers. The visual comparison of the phantoms generated at different voxel size confirmed an improved quality of simulated anatomical structures, as reflected in reduced quantization artifacts. Our results about the refinement of the breast anatomy simulation have been published in the proceedings of the 2011 AAPM conference, and submitted for publication in Medical Physics journal.

We have also proposed a simulation of the partial volume effects in software breast phantoms. The partial volume effect occurs when a phantom voxel contains more than one simulated tissue type. The corresponding physical properties (e.g., the linear x-ray attenuation coefficient) of such simulated phantoms depend on the proportions of simulated tissues in each voxel. Simulation of the partial volume effect can help improve the equality of synthetic images of the phantom (e.g., by reducing the visibility of digitization artifacts) without requirement to further reduce the voxel size. To support the simulation of the partial volume effect, we developed an efficient method for estimating the proportion of the two tissues simulated in a voxel, based upon

the planar approximation of the border between the tissues, and comprehensive analysis of possible orientations of the border relative to the voxel. In addition to the partial volume simulation, the developed method has potential applications in solving other computational geometry problems. Our current results in the simulation of the partial volume effect has been submitted for presentation at the 2012 SPIE Medical Imaging conference.

- o Specific Aim 1: Primary study (Drs. Liu, Shi, Pokrajac, and Wilson) Measure the racial dependence of image-based risk biomarkers. (Y1-Y3);
- o Specific Aim 2: Exploratory study 1 (Drs. Pokrajac, Shi, and Liu) Investigate improvements to a breast cancer risk prediction model for AA women. (Y2-4); and

For the purpose of supporting the estimation of the image-based risk biomarkers from the ACRIN clinical data, we adapted a general breast image analysis pipeline, developed in the lab of Dr. Despina Kontos at UPENN. The breast image analysis pipeline (consists of an array of quantitative image analytics for breast density estimation and parenchymal texture analysis in digital mammography (DM) and digital breast tomosynthesis (DBT) images. Fig. 1 shows the image processing steps in the imaging biomarker analysis pipeline.



**Figure 1:** The flowchart of the image processing steps in our breast imaging biomarkers pipeline.

The breast density analysis employs a fully-automated breast percent density (PD%) estimation technique based on an adaptive multi-class fuzzy-c-means algorithm. Parenchymal texture analysis: We developed a fully-automated software pipeline to perform quantitative analysis of breast tissue composition from multimodality digital breast images. The integrated image analytics consist of an initial image quality (IQ) test, in which a query/testing is performed in the DICOM header files of the digital images to validate acceptable dose and acquisition parameters (i.e., kVp, exposure, compression, etc.). Subsequently, the pipeline incorporates a preprocessing step with an option to create a regional tissue mask from which the imaging parenchymal pattern descriptors are extracted.

Texture analysis is performed by extracting multiple image texture descriptors, and offering a range of optimization and image processing parameters, as well as the first-order statistics of the original breast image and the stochastic fractal dimension image, and second-order statistics extracted from the co-occurrence and run-length matrices. The pipeline provides the option of defining regional masks for feature extraction, including the entire breast or the predominantly fibroglandular tissue region as segmented by the density estimation algorithm. For volumetric image datasets both tomographic and volumetric texture analysis methods have been implemented. Statistical information for any desired feature (e.g., mean, median, skewness, and central-moments) can be calculated for any image set. A two-level feature merging approach combining principal component analysis (PCA) with independent component analysis (ICA) is used to compute a breast composition imaging biomarker vector.

- o Specific Aim 3: Exploratory study 2 (Drs. Wilson, Pokrajac, and Liu) Explore potential racial differences in genetic determinants of breast density. (Y2-Y4)

The start of the exploratory study of the genetic determinants of breast cancer has been delayed due to unavailability of genetic sequencing kits at Penn. We will continue to check the availability, and if possible revisit this Specific Aim in the future.

- o Prepare peer-review publications on the results of the proposed research. (Y3-Y4)

While working on the current research, we have prepared several publications about our results. These publications are listed in the section on “Key Research Accomplishments”.

- o Validate success of the research training program by annual teleconferences with and bi-annual visits by external Advisory Committee.

On Wednesday, Nov. 3, 2010 at 3:30-4:30pm, a teleconference meeting of the DoD award Advisory Committee was organized by Drs. Maidment, Liu, and Bakic, and attended by all the DSU faculty supported on the grant, as well as Drs. Chanita Hughes and Timothy Rebbeck from Penn. The discussed issues include our progress on the grant, future research steps related to the genetic analysis project aims, as well as the long term aim of establishing a regional Breast Cancer Disparity Center at DSU.

DSU faculty met with UPENN mentors on June 24, January 24, 2011 and August 9, 2010 to discuss the progress and the future work of each DSU faculty.

Among additional collaborative activities between the Penn and DSU, Drs. Pokrajac, Maidment and Bakic are currently supervising two Penn graduate students during their course project for the class on Biomedical Image Analysis (CIS537). The students have been working on the quantification and characterization of simulated phantom shapes using geometrical methods. The results of this project have been submitted for presentation at the 2012 SPIE Medical Imaging conference.

We will continue the above mentioned research. Computational resources will be utilized at DSU to migrate appropriate research subprojects with the increasing involvement of undergraduate and graduate students. Preliminary data from the ongoing ACRIN percent density studies and emerging information on biomarkers related to minority populations and breast density will direct further investigations. Based upon our current results in the refinement of the breast anatomy simulation, we also consider preparing an NIH R01 research proposal on the continuing development of the software breast phantom for the purpose of efficient generation of large number of phantoms with small voxel size. The submission of the proposal is anticipated for Winter 2011 or Spring 2012.

### **3. Key Research Accomplishments**

- We completed the transfer of all mammograms requested from the ACRIN 6652 study, including ~11,000 anonymized, previously acquired cases; all the images were copied at DSU and UPENN;
- We developed a storage service (MIRC) database to host the ACRIN clinical data, and support their analysis.
- We developed an SQL based database query to search for cases with only partial breast visualization. Those cases cannot be analyzed by the current standard methods for the estimation of image-based risk biomarkers, since the methods are designed to expect as input a single mammographic image.
- Using the developed query we analyzed an existing database of anonymized clinical mammograms at UPENN (including images of 657 patients from previously completed PPG study), and found ~13% of cases to have only partial breast visualization. This percentage justifies our research activities on developing an image/data fusion method for the estimation of biomarkers in cases with only partial visualization.
- To validate the proposed methods for image/data fusion we developed a novel algorithm for the simulation of breast anatomy. Synthetic images of the software breast phantom provide the known



ground truth (for quantitative validation), and flexibility to cover clinically observed anatomical variability.

- We developed a conceptual design of a system for the analysis of the ACRIN data. The system includes an interface connecting the MIRC database with an analysis pipeline for the estimation of image-based risk biomarkers.
- We adapted the general breast image analysis pipeline (developed in Dr., Kontos' lab at the UPENN) to be used for the analysis of the ACRIN data

#### **4. Reportable Outcomes**

##### **Publications (journal papers and conference proceedings):**

- Xia, S., Liu, F., Maidment, A.D.A., Bakic, P.R.: "Refinements to the Deformation Model of An Anthropomorphic Computer Generated Breast Phantom," Medical Physics 37: 3131, 2010. (Presented at the 2010 Annual Meeting of the American Association of Physicists in Medicine, Philadelphia, PA.)
- Pokrajac, D., Maidment, A.D.A., Bakic, P.R.: "A Method for Fast Generation of High Resolution Software Breast Phantom," presented at the 2011 Joint Annual Meeting of the American Association of Physicists in Medicine and Canadian Organization of Medical Physicists, Vancouver, BC.)
- Bakic, P.R., West, E., Sak, M., Gavenonis, S.C., Duric, N., Maidment, A.D.A.: "Comparison of 3D and 2D Breast Density Estimation from Synthetic Ultrasound Tomography Images and Digital Mammograms of Anthropomorphic Software Breast Phantoms," SPIE Medical Imaging 2011.
- Pokrajac, D., Maidment, A.D.A., Bakic, P.R.: "Optimized Generation of High Resolution Breast Anthropomorphic Software Phantoms," submitted for publication in Medical Physics, 2011.
- Chui, J., Pokrajac, D., Maidment, A.D.A., Bakic, P.R.: "Roadmap for Efficient Parallelization of Breast Anatomy Simulation," submitted for presentation at the 2012 SPIE Medical Imaging conference.
- Chen, F., Pokrajac, D., Shi, X., Liu, F., Maidment, A.D.A., Bakic, P.R.: "Partial Volume Effect Simulation in Software Breast Phantoms," submitted for presentation at the 2012 SPIE Medical Imaging conference.
- Contijoch, F., Lynch, J., Pokrajac, D., Maidment, A.D.A., Bakic, P.R.; "Shape Analysis of Simulated Breast Anatomical Structures," submitted for presentation at the 2012 SPIE Medical Imaging conference.
- Liu, F., Bakic, P.R., Pokrajac, D.D., Wilson, C., Shi, X., Maidment, A.D.A.: "Image Based Biomarkers of Breast Cancer Risk: Analysis of Risk Disparity Among Minority Populations", Presented at the 2011 DoD Era of Hope Meeting, Orlando, FL, 2011.

#### Invited Presentations:

- Bakic, P.R. and Pokrajac, D.D.: “Advanced Design of Anthropomorphic Software Breast Phantoms: Work in Progress”, Invited talk at the DSU/Penn Breast Cancer Basics seminar, Dover, DE, Dec. 2010.
- Pokrajac, D.D. and Bakic, P.R.: “Computer Science Issues in Modeling Breast Tissue “, Invited talk at the Computer Science Club, Delaware State University. Dover, DE, Feb. 2011.

#### Patent Applications:

- Pokrajac, D.D., Bakic, P.R., Maidment, A.D.A., “Techniques for Simulation of Multi-dimensional Spatial Regions,” Provisional Patent Application, University of Delaware/Delaware State University, (DSU No. 12-01), 2011.

### **5. Conclusion**

During last year, we focused on training and research. Among the training activities, we organized and attended DSUPENN Breast Cancer Seminars and other UPENN seminars, took graduate courses at UPENN, and jointly supervised Penn and DSU graduate students. Jointly performed research activities on the Award project include transferring the ACRIN clinical data and developing an appropriate MIRC storage service; estimation of the prevalence of cases with only partial breast visualization and development of the image/data fusion method for such cases; adapting a breast image analysis pipeline to be used for biomarker estimation; developing an interface between the MIRC database and analysis pipeline. Such a configured system is now ready to support the estimation of image based risk biomarkers for the analysis of racial disparity, and prospective refinement of the breast cancer risk prediction methods.

## **6. References**

N/A

## **7. Appendices**

N/A